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Characteristics of Artificial, Gypsified and Natural Gypseous Soils under Dry Condition

Abstract- Gypseous soil characteristics were studied types many researchers, but the bearing capacity of sandy gypseous soil with different preparing of the soil models were tested in dry condition under static and cyclic loads in this study, three types of gypseous soils are prepared (artificial, gypsified and natural gypseous soils). The laboratory tests were needed to evaluate geotechnical soil properties. The main objective of this study is testing of the soil models in dry condition for measuring earth pressures with displacements of the soil models under monotonic and repeated loads within relatively large manufactured physical model. The results found that the natural and gypsified soils have displacements of about (1 to 2 cm) and the pressures of earth reaches to about (500 – 550 kPa) and the artificial gypsified soil reaches to (600 - 650 kPa) and the displacement of about (1 cm). SO₃ content tested for the soil samples reaches to about (11.7 %) for gypsified and natural soils while reaches about (24.5 %) for artificial gypseous soil.

Keywords- artificial gypsified soil – natural gypsified soil – natural gypseous soils.

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1. Introduction

The gypseous soils was a collapsibility soil upon wetting because of its unpredicted properties. Gypseous soil introduced several changes in their chemical and physical properties when exposed to water [1]. Gypsum was a type of salts that can be dissolve in water and the particles transported when the leaching process were happen. Gypsum may present in soil as one or combination of the following forms [2]:

1. Hydrated gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), crystalline form.
2. Anhydrite gypsum (CaSO_4), crystalline form.
3. Al-Baster, non-crystalline form of gypsum. Fine grain – usually massive, light color.
4. Secondary gypsum, crystals in surface layers, sometimes crust or re-crystalized from evaporated ground water.

Secondary or detritus and pre-precipitated gypsum, crystals in surface layers, sometimes crust or re-crystalized from evaporated ground water.

Secondary gypsum which may be formed by (Buringh, 1960) [3]:

1. The primary gypsum rocks dissolved and precipitated in younger formation in both crystalline and amorphous forms.
2. Accumulation in the layer above the capillary water zone as a result of evaporation of ground water in arid areas.

3. Windblown secondary gypsum forms the gypseous desert area and deposited on other soils, or precipitated from irrigation water.

The main character in dry condition was the bearing capacity of each test under a general shear failure at static and cyclic loading [4] for three types of soils (natural gypseous, natural gypsified and artificial gypsified soils).

For the previous studies, some researchers study the gypseous soils with different methods using devices for tests, at dry condition under static or cyclic loads on natural gypseous soil models, but a little deals with gypsified and artificial soil models, some of these studies were shown in this study as follows:

Al-Qaissy, investigate gypsum migration process resulting a gypsum concentration with different gypsum content in soils, and its effect on compressibility and shear strength. Simulation of the natural field conditions were furnished to these samples in the laboratory. The testing program was conducted at different ages of 0, 1, 3, and 6 months in order to study time effect. The test results reveal that, migration process of gypsum took place in the simulated gypsified samples, causing leaching of gypsum in certain zones. The soil exhibited lower compressibility and higher collapsibility characteristics as the gypsum content increased under leaching process, time progression and gypsum precipitation associated with the migration process. Whereas the leaching increased the compressibility. The

increase in gypsum content of the soil reduced the cohesion component of shear strength c' , while it increased the angle of internal friction ϕ [5]. Jaume Porta, studied of gypsum complementary and necessary to obtain a general overview of the main methodologies and techniques used to characterize and range from the gypsum identification in soil surveys and determination have been developed in the field of gypsum in the laboratory with its own limitations especially in gypsiferous soils of semiarid and arid regions [6]. Al-Obaidi, "Three types of collapsible soils have been experimented; sandy gypseous soil from Iraq, silty loess soil from Germany and a mixture of 70% artificial gypsum with 30% Silber sand. A series of single and double Oedometer collapse tests were carried out. ESEM-EDX analysis at different states of the soil samples. The results indicate that the selected soil samples exhibit a significant collapse volume change in response to single and multi-steps wetting under constant net vertical stress. The collapse potential is stress path dependent and is a function of net vertical stress and initial void ratio" [7].

2. Laboratory test

1. Text Citations

Three samples of soils are prepared in laboratory. The first sample is natural gypseous soil bring from Wady-Sheshen region in Salah-alddin governorate. The second sample is natural gypsified soil prepared in laboratory as method and the third sample prepare by mixing of gypsum treated in facility with the same sand of collected gypseous soil in the second sample, then the kind of gypseous soils used are three (natural, gypsified, and artificial gypseous soil). The artificial gypsified gypseous soil was very hard and solid material because of high surface area for that reason the voids decrease when the artificial gypsum content increased, while the natural and gypsified soils void ratio is increase under increase in gypsum content. Bearing capacity of artificial gypsum was and larger than the natural gypseous and gypsified soils. Secondary or detritus and pre-precipitated gypsum, crystals in surface layers, sometimes crust or re-crystalized from evaporated ground water [1, 2 and 3], and (gypsum burned in the facilities on 130 C° and treated to fine grained with very high of surface area are used in this study. The first aim of this study is to find the difference between natural gypsum soil and artificial or manufactured gypsum soil. In the mixing of the artificial gypseous soil, three samples with different artificial gypseous percent

(23, 34, and 51 %). The soil of about 51% gypsum content was used for all samples as a worst state. The kneading and mixing of the artificial gypseous soil done using the mixer or grinder as shown in the Plate 1. Also amount brought of free gypsum (95% secondary gypsum) with help of the General Authority for Geological Survey and Mining / Baghdad.

3. Methodology

Soil model container for physical model with dimensions about (100 cm length \times 40 cm width \times 70 cm height), the model system is manufactured in the workshop and training centre at University of Technology (UOT). Plate (2) shows physical soil model installed in lab.



Plate 1: Mixer of samples materials for the artificial and gypsified soil samples



Plate 2: Two soil model containers were manufactured prepared for testing



Plate 3: Computerized (PLC) of static and cyclic loads apparatus system with physical soil model during testing

The model apparatus system for monotonic and repeated loads found in soil lab at UOT consists of three main parts: hydraulic and mechanical system with connection to computerized (PLC) system. The piston connected with footing (40 cm

x 20 cm) to apply loads on soil model system as shown in Plate 3.

The instrumentation for measurements used in the testing program were:

- 1) Pressure cell with data logger to measure the earth pressures, shown in Plate 4.
- 2) Linear variation differential transducers with data logger to measure the displacements, as shown in Plate 5.
- 3) Pressures and displacement reading on the surface of the soil models using monotonic and repeated apparatus loading system as shown in Plate 3.

The data from the model apparatus reading by using (SIMATIC-V4.0) program transferred to computerized (PLC) of the static and cyclic system apparatus on the surface of the ballast layer on soil model. While the sensors with data loggers using the (Jmida program) on computer to transfer data measured in the 25 cm depth of 50 cm total soil model layer .

Artificial and natural gypsified soils, and natural sandy gypseous soils were collected and prepared to study the behaviour of these types of soils under dry condition, and monotonic and repeated loading was applied on the tested soil model [8 .] After examined the soil with the conventional laboratory tests to evaluate the soil properties, the artificial gypseous and gypsified soils were prepared as shown in (Al-Qaissy, 1989) [5], grinding the soil to the required gradation then the soil prepared in the container of soil model with five layers each layer 10 cm depth until reaching to required maximum dry density and optimum moisture content. All the important sensors were placed on the soil at 25 cm level representing the mid height of the total soil depth. The sensors placed in the physical soil model as shown in the Plate 6.



Plate 4: Earth Pressure Cells with data logger



Plate 5: Displacements system (LVDTs) with data logger

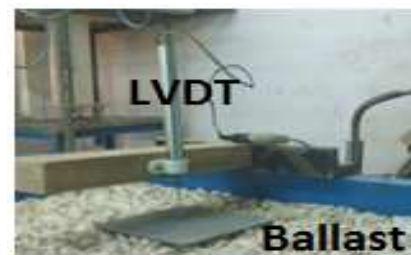


Plate 6: LVDT install during preparing soil model

After preparing the last layer, placing the ballast (crashed marble with suitable gradation for damping of energy) as the final layer on the soil model.

4. Laboratory Tests Results

The physical properties for the artificial gypsified (N_1), natural gypsified (N_2) and natural gypseous (N_3) soil samples were shown in the Table 1.

I. Physical and Mechanical tests

The gypsum content according to (Al-Muftly and Nashat, 2000), [9] and hydrated method (SO_3) as shown in Table 1.

Table 1: Physical properties for three types of soil samples

Sample	N_1	N_2	N_3	Specification
Liquid Limit L.L %	27	24	22	BS:Part2: 4.3, sec.2.6.6[10]
Plastic Limit P.L %	23	20	18	BS:Part2: 4.3, sec.2.6.8[10]
Specific gravity G _s	2.44	2.42	2.46	ASTM D 845-02 (with kerosene)[11]
γ_{dry} (kN/m ³)	16.15	16.42	16.83	(ASTM- D698: 2012)[12]
O.M.C.%	17.3	16.6	15.9	(ASTM- D698: 2012)[12]
Dry or Al-Muftly method %	51.43	50.37	51.86	(Al-Muftly and Nashat, 2000)[9]
G.C. by SO_3 or wet method %	51.65	51.43	52.11	BS: Part3:5.3, sec. 5.6.3[13]
SO_3 %	24.03	23.92	24.24	-----

Where:

N_1 : Natural soil from Tikrit city (Wady-Shesheen area). N_2 : Gypsified soil prepared in lab using natural gypsum with sand of Wady-Shesheen area.

N_3 : Gypsified soil using artificial or processed gypsum in factory with sand of Wady-Shesheen area.

II. Particle size distribution

The particle size distribution for the three soil samples shown in Figure 1, according to wet sieving with kerosene (non-polar solvent) [14 and 15] and (BS: 1377:Part2:1990:9.2, 4.6.4), and Hydrometer test (BS1377:Part2:1990:9.5) according to [16 and 17].

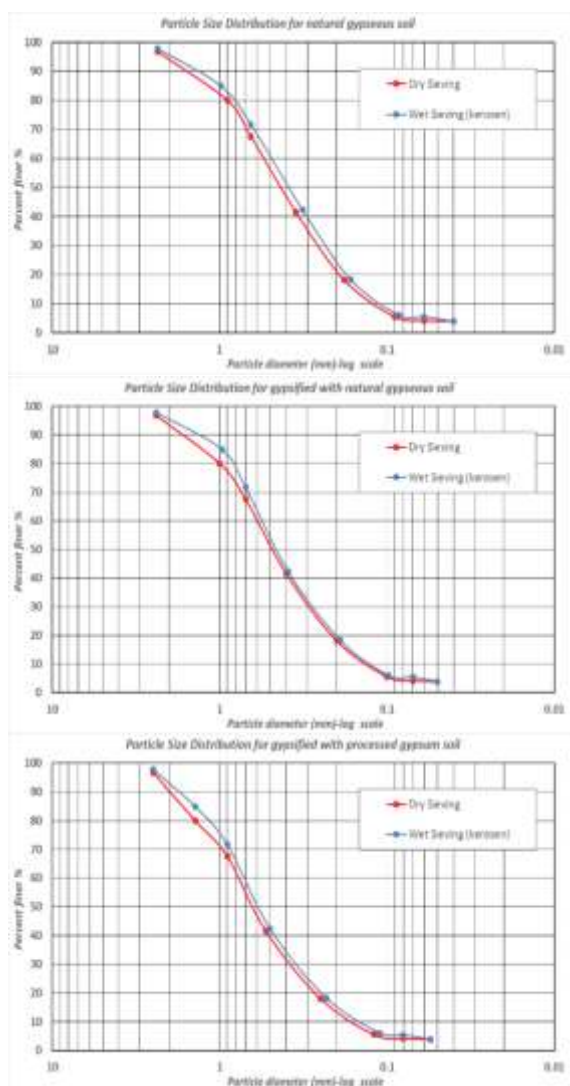


Figure 1: Particle size distribution (natural, gypsified and artificial gypseous soils)

III. Compaction test

According to (ASTM-1557 Modified Procter, Method A) [18], the results of three soil samples for compaction test, as shown in Figure 2.

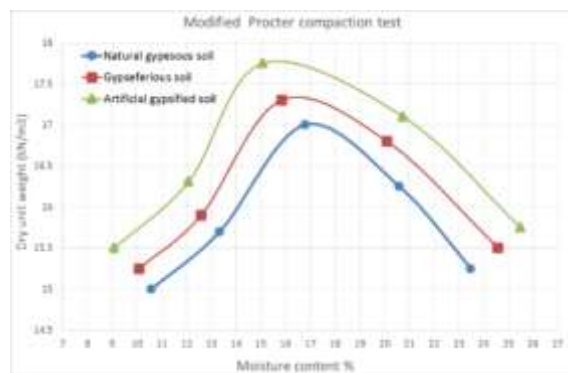


Figure 2: Results of compaction test for three soil samples of gypseous soil

IV. Single collapse test

According to (BS 1377: part 5: 1990) [19] the results for the collapse test, of the three types of soils are shown in the Figures 3.

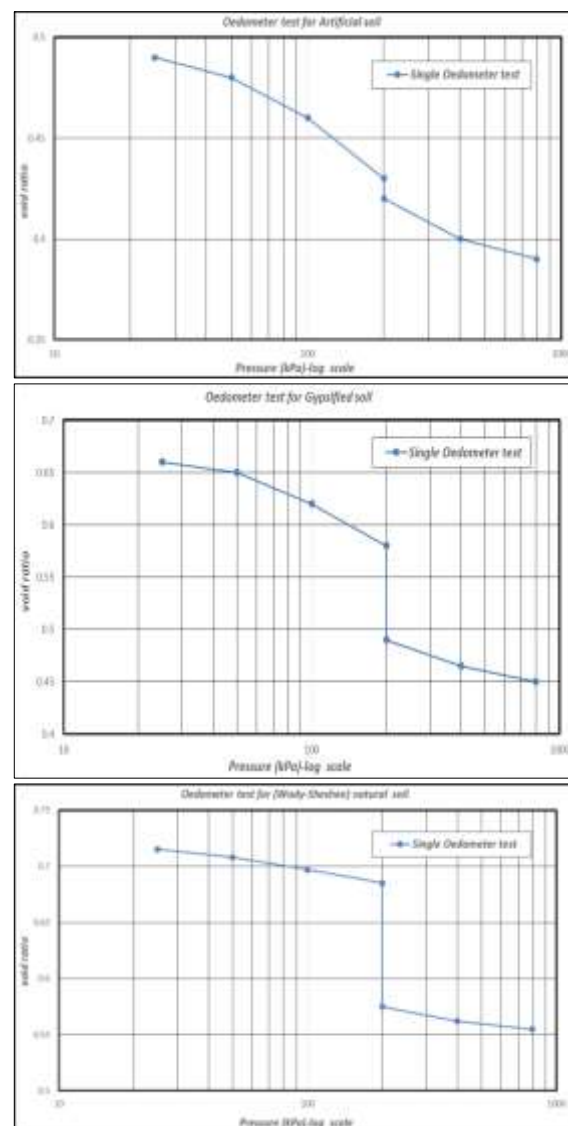


Figure 3: Results of single collapse for soil samples gypsum soil sample

V. Direct Shear test

The direct shear test according to (ASTM-3080-7), [18] is applied to the three soil samples were tested in the direct shear instrument to get shear soil parameters (c and Φ), and the results are shown in the Figure 4.

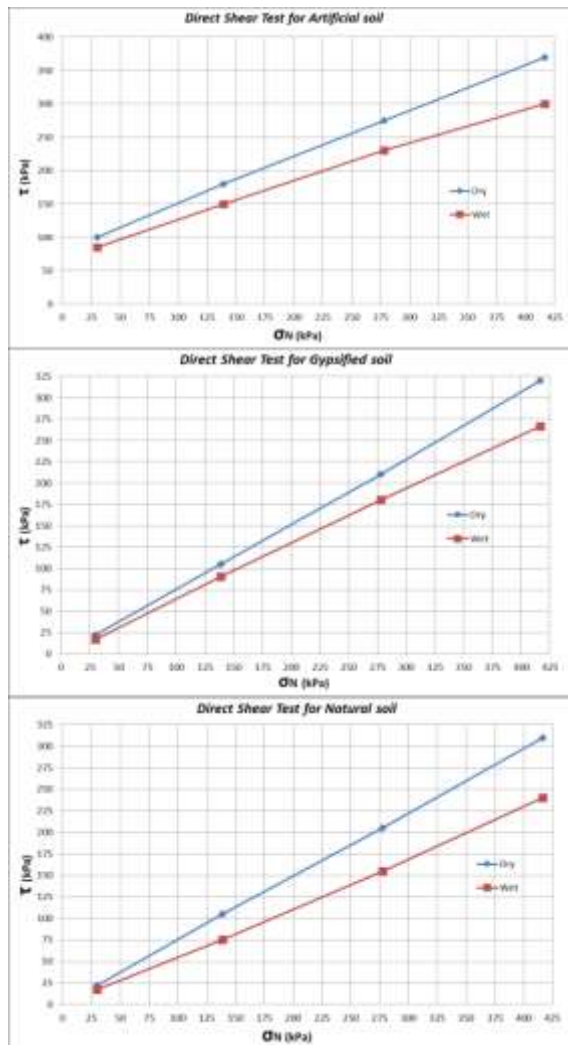


Figure 4: Results of direct shear test for soil samples of gypseous soil

5. Results Presentation

There are (6 models) tested within a group of three soil samples with dry condition under monotonic and repeated loads. All soil samples with 51% gypsum content. The procedure of the testing program included the following tests summarized in the flowchart of Figure 5.

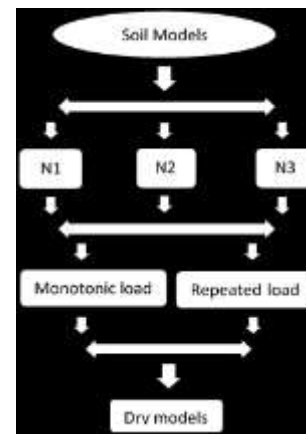


Figure 5: Flowchart for testing program for the study

I. Dry Models

The group of samples were consists of three types of gypseous soils (artificial, gypsified and natural soils). The result for each model in the group can be summarized in Table 2 as follows:

Table 2: First and second groups testing results of samples for dry condition under monotonic and repeated loads

	Monotonic load		
Sample	N_1	N_2	N_3
P_{PLC}	675	500	400
Pe	625	450	350
Disp.	10	15	20
TL	8000	4500	4000
	Repeated load		
$P_{Dyn.}$	260	240	220
P_{PLC}	650	450	350
Pe	600	400	300
Disp.	5	10	15
TL	26000	24500	23000
N	52000	49000	46000

Where:

- $P_{Dyn.}$ = 40% of static pressure (kPa).
- Pe = access earth pressure (kPa),
- P_{PLC} = Pressure of the model apparatus (kPa),
- Disp. = Displacement (mm).
- TL = Time of loading (sec.).
- N = No. of stress cycles (cycle).

1. Earth Pressures and displacements for models at Monotonic Load

The earth pressures at first model (M1) shows that maximum load at failure of soil is about (625 kPa) in dry case. For this model the surface earth pressure is about (650 kPa) and LPDTs or LVDTs is about 5 mm, Figure 6.

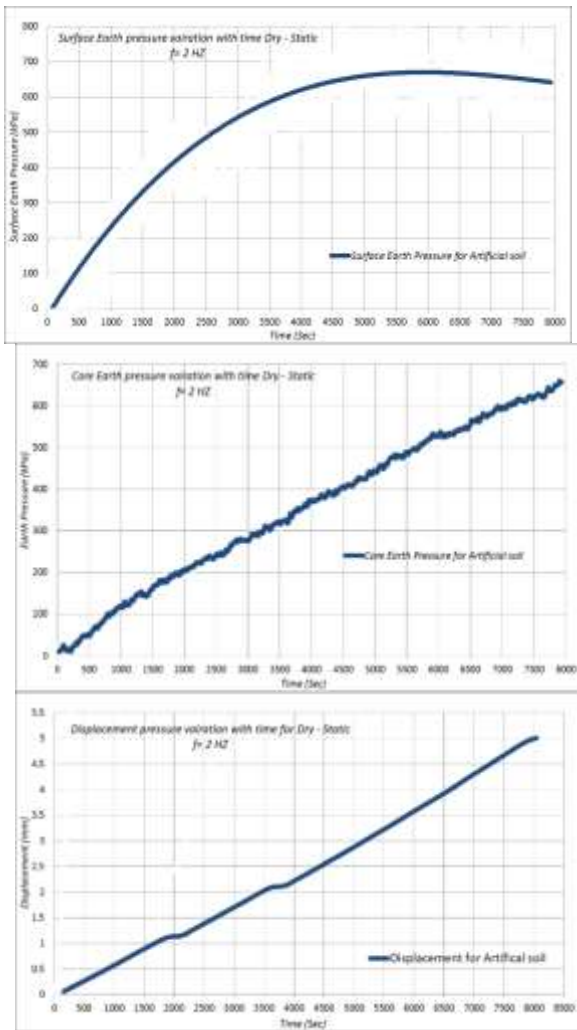


Figure 6: Surface and Earth Pressures, and Displacement of M1 Model (Monotonic - artificial)

The pressure on surface of the soil model with a higher amplitude and a little disturbances during applying the load while the earth pressure was behave as a linear relation with lower amplitude that was attributed to the effect of apparent cohesion of fine particles with a high surface area of artificial gypsum, this give a different behavior comparing with the behavior of soil in the core of the model, the displacement was a straight forward behavior but with a little disturbances at about 200 and 3600 sec.

The earth pressure of model (M2) for gypsified soil reaches to about (450 kPa) in dry case. The pressure of PLC and displacement are (500 kPa) and 15 mm respectively, Figures 7.

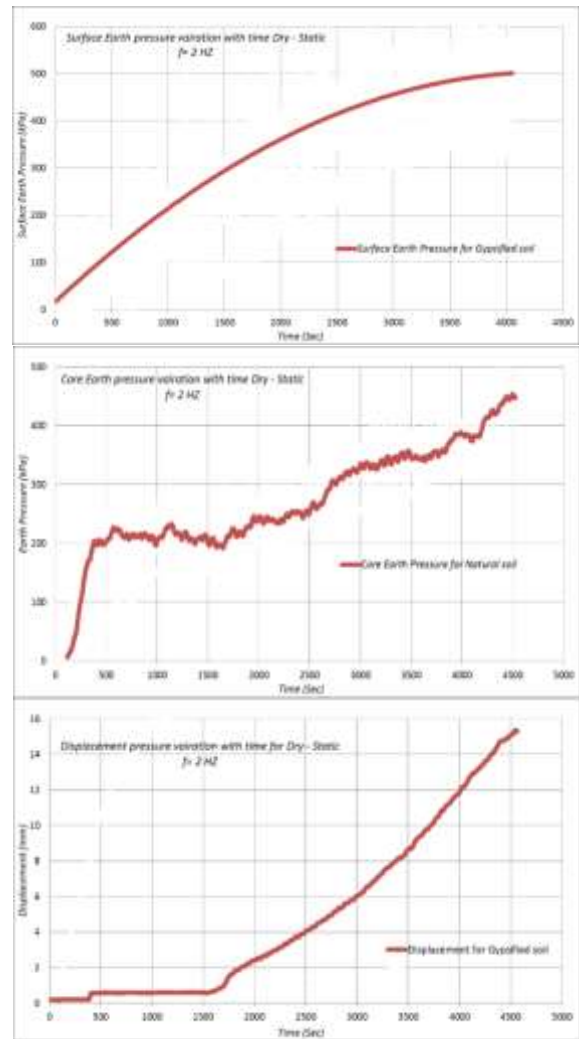


Figure 7: Surface and Earth Pressures, and Displacement of M2 Model (Monotonic – gypsified)

There are similarity in behaviour between the natural and gypsified soil model with some differences in pressures and displacement that attributed to the effect of remoulding of the sandy gypseous soil, with curvature behave instead of linear in earth pressures and sudden collapse from 1500 to 2250 sec. The apparatus pressure with higher amplitude behaviour that attributed to the gypsum content with natural behaviour in this model.

The earth pressure at model (M3) shows that maximum load at failure of soil was about (350 kPa) in dry case. The pressure of PLC and displacement are (400 kPa) and 20 mm respectively, Figure 8.

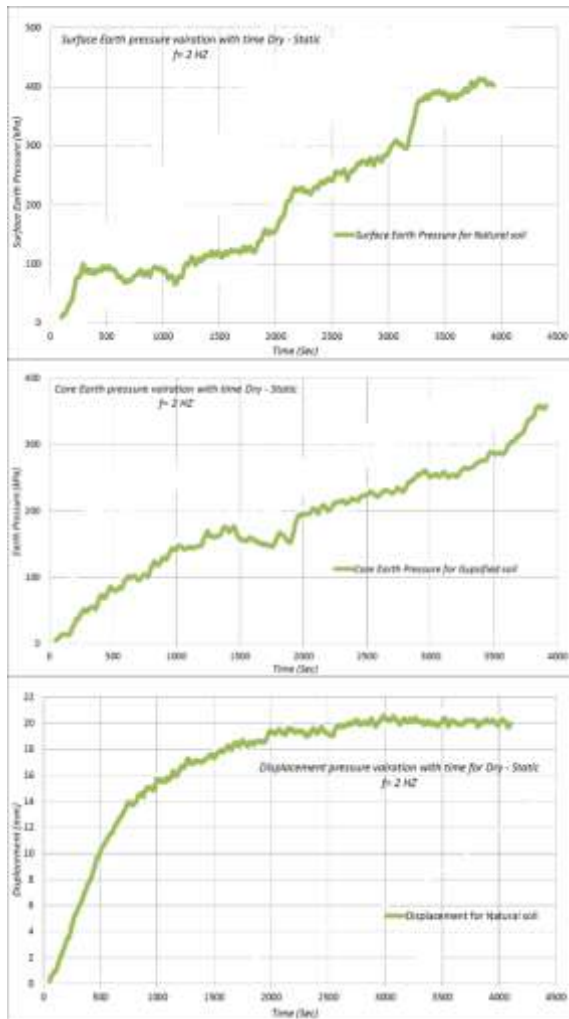


Figure 8: Surface and earth pressures with settlement for M3 Model (Monotonic - Natural)

The summary of the bearing pressures for three models of dry condition shown in Figure 9.

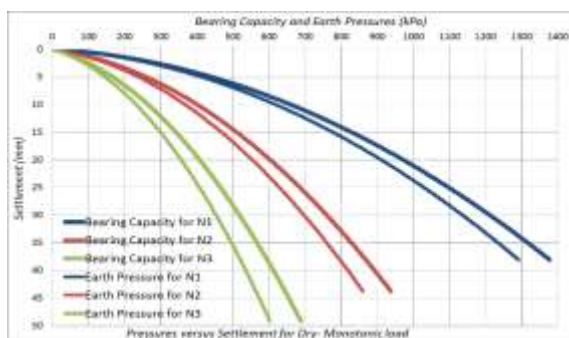


Figure 9: Bearing Capacity with settlement for M1, M2 and M3 Models (Monotonic load).

2. Earth Pressures and displacements for models at Repeated Load

The earth pressure at model (M4) under initial repeated load equal to 40% from monotonic load at failure (260 kPa) for artificial soil and reaches to about (650 kPa) in dry case. The surface earth pressure and displacement are (650 kPa) and 5 mm respectively, Figure 10.

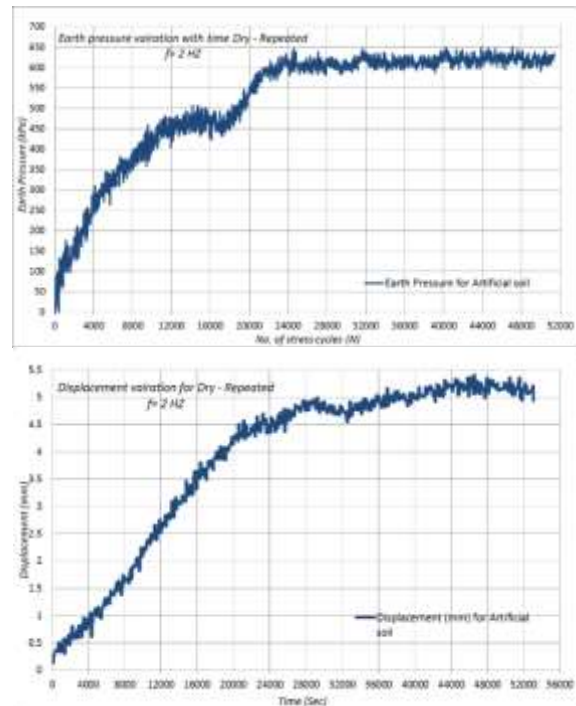


Figure 10: Surface and Earth Pressures, and Displacement of M4 Model (Repeated - artificial).

As shown in artificial dry monotonic test, the behaviour shows high bearing capacity pressures with very low displacement. In this test with cyclic load, the behaviour approximately the same with a little differences. The apparatus pressure was rising until 10000 sec then rapid rising in short period with a little changes in amplitude and continue with constant rate of rising, the same behaviour in earth pressure but with rapid rising at the beginning time until reach 10000 sec then after that continue with a constant value until the end of the test, this means that the earth pressures reaches to steady increase after 10000 sec and at the same time with increasing of apparatus pressure with a constant rate, that means the soil reaches to the minimum void ratio in dry condition and continue to carry out the loads until reaches maximum value of pressure in the test. This behaviour may be attributed to the artificial gypseous soil characteristics.

The earth pressure at model (M4) under initial cyclic load equal to 40% from static load at failure (240 kPa) for artificial soil and reaches to about (400 kPa) in dry case.

The surface earth pressure and displacement are (450 kPa) and (10 mm) respectively, Figure 11.

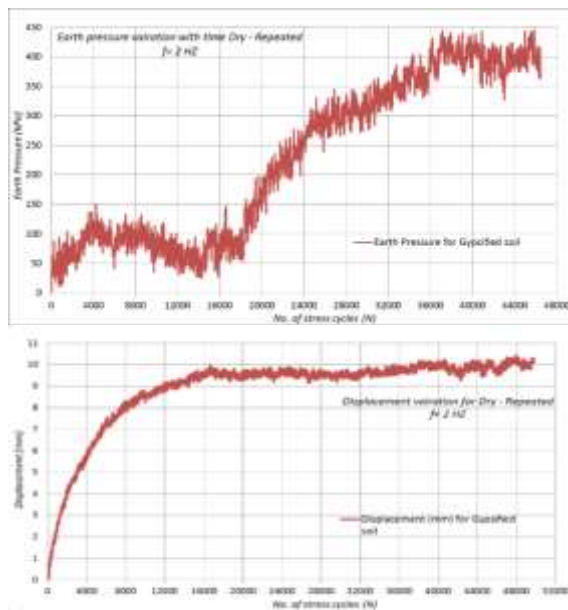


Figure 11: Pressure of PLC, Earth Pressure and displacement for M5 Model (Repeated - gypsified).

The behaviour of gypsified soil at repeated load have a little different since at the begin of test to about 8000 sec there are some disturbances in pressures of earth pressures but rapid rising in a short period with moderately rapid rate until reach to steady rate values, the displacement with similar behaviour, rapidly rising in the first time until about 8000 sec then gradually rising until reach the steady rate.

The earth pressure at model (M6) under initial repeated load equal to 40% from static load at failure (220 kPa) for artificial soil and reach to about (300 kPa) in dry case. The surface earth pressure and displacement are (350 kPa) and 15 mm respectively, Figure 12.

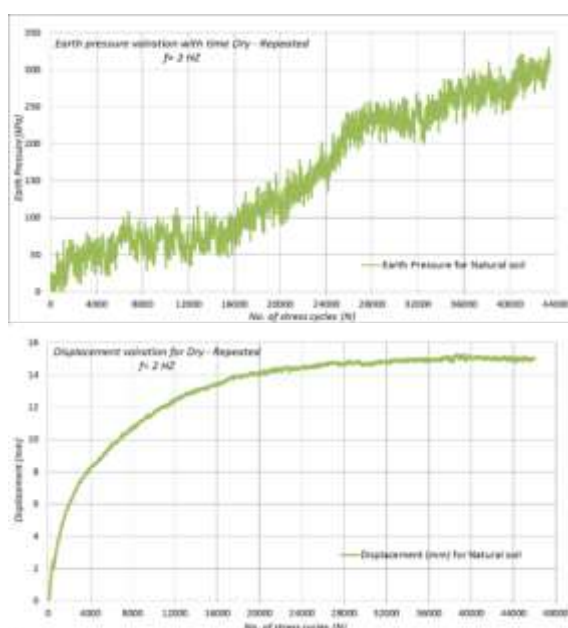


Figure 12: Displacement for M6 Model (Repeated - Natural).

Surface earth pressure rising approximately linearly with a little disturbances during the test, while the earth pressure was rising until 8000 sec then increases of rate of rising until reaches to the steady rising at 16000 sec, while the displacement was steady rising from the beginning to the end of the test, that is maybe attributed to the naturally behaviour comparing with the other similar previous tests.

6. Chemical data for gypseous soil models of the testing program

Determination of SO₃ was according to (BS 1377: Part 3: 1990:5.2, sec.5.6.2) [20] and determination of TDS was due to (BS 1377: part 3: 1990: 8.3) [21] and [22], the three types of soil samples tested in soil lab.

After presentation of the results of the TS, TDS, TSS and SO₃ interpretation shows that the results among these parameters are shown in Table 3 as follows:

I. Dry condition

Table 3: First and second groups results of samples at dry condition under static and cyclic loads.

Sample	Monotonic load		
	N ₁	N ₂	N ₃
TDS	1000	1100	1150
TSS	450	495	517.5
TS	1450	1595	1667.5
SO ₃	11.63	23.5	23.3
G.C.	25	50.5	50.1
Sample	Repeated load		
	N ₁	N ₂	N ₃
TDS	1000	1150	1200
TSS	450	517.5	540
TS	1450	1667.5	1740
SO ₃	11.16	23.25	23.02
G.C.	24	50	49.5

Where:

- TDS = Total dissolved salts for leachate water.
- TSS = Total soluble salts.
- Total Solids = TSS + TDS.
- G.C. = gypsum content.

7. Statistical models

By using STATISTICA program for simulating the experimental work, the 3D contour areas shows a good agreement with testing models in lab as shown in Figure 13, for six numerical models of the soil testing program. The results of

statistical program can be tabulated in the Table 4 to show the results and made a comparison with

the same results obtained in the experimental work [23].

Table 4: the four groups results of samples at dry and leaching conditions under static and cyclic loads.

Dry condition		Monotonic load	
Sample	N_1	N_2	N_3
$Pe_{max.}$	650	450	350
$De_{max.}$	5	15	20
$T_{max.}$	8000	4500	4000
Dry condition		Repeated load	
Sample No.	N_1	N_2	N_3
$Pe_{max.}$	650	400	300
$De_{max.}$	5	10	15
$T_{max.}$	8000	24500	23000

Where: $Pe_{max.}$ = maximum earth pressure (kPa).

$De_{max.}$ = maximum Displacement (mm).

$T_{max.}$ = maximum Time of loading (sec.).

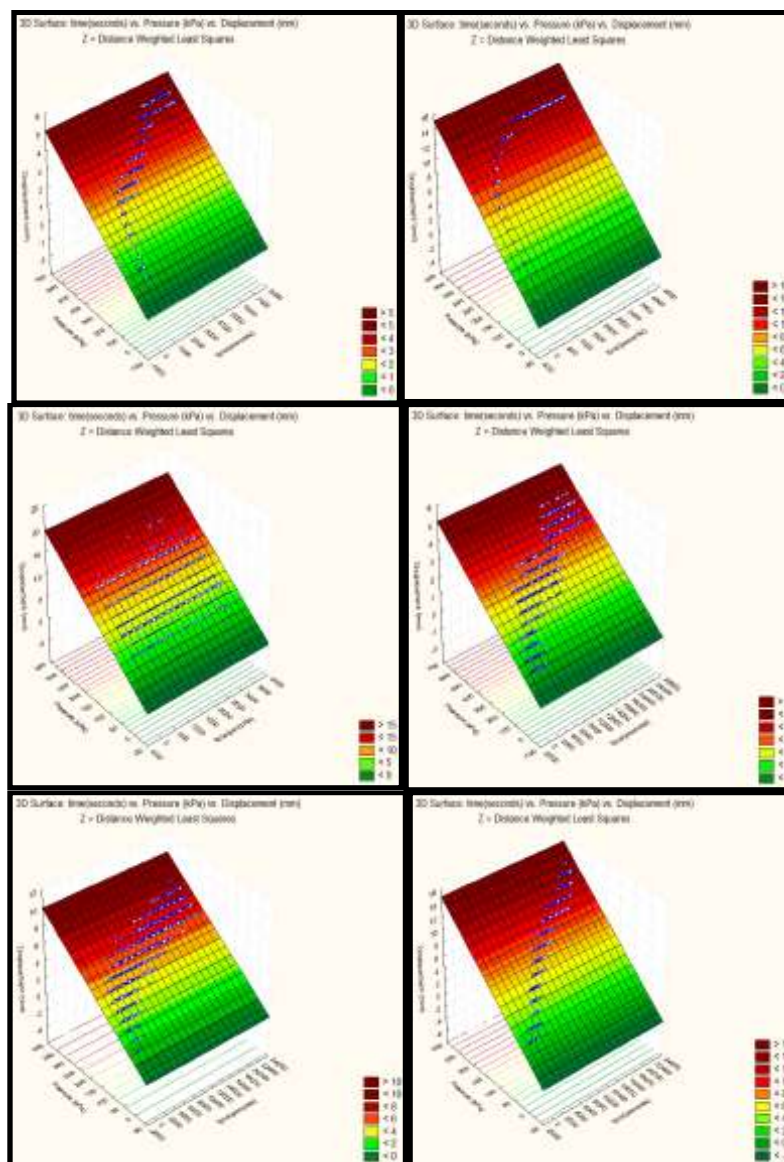


Figure 13: 3D contours areas for M1, M2, M3, M4, M5, and M6.

8. Interpretation Discussion

The models of dry condition shows that monotonic and repeated loads reaches to the maximum bearing capacity for each three types of soil. The displacements appears has approximately a constant low values in artificial models, while a little higher values in the other two types of soil, that attributed to the higher ability for the strong bonds between gypsum and soil in artificial type of soil because of the treating (kneading and grinding and burning with 130 Co of particles in the factories to produce a purity gypsum with a higher surface area) that has a property to made a higher decreasing in the void ratio with a higher increasing in bearing capacity and lower the displacement behaviour, that means the artificial soil has wide different in some geotechnical characteristics such as void ratio, and compressibility. The artificial soil behaviour give indication that this soil has higher bearing capacity than natural and gypsified soils, especially when increasing gypsum content over than about 40%.

The statistical models shows that the most soil models have a good agreement between the experimental and theoretical models with about 95%.

9. Conclusions

The artificial gypseous soil cannot be used in geotechnical studies, while the natural gypseous and gypsified soils behaviour used in geotechnical studies. Concluding that the gypsified soils are prepared and used in the geotechnical study with a little improving and controlling samples on properties with remoulding by gypsifying the soil comparing with natural soil. The behaviour of the natural gypsum are different after burning at (130 Co) with mixing and grinding to produce gypsum with very higher surface area because of the change happen at the structure of salts particles when lose the water between the bonds of the salt, this new properties give the artificial soil strong bonds with sand as a filler after reactions rapidly with adding of water.

The gypseous soil characteristics are more accurate at larger scale model than conventional laboratory samples in lab tests or small sample models, and using the sensors and data loggers compatible with the physical model used for measuring the soil properties.

The artificial gypseous soils has higher bearing capacity and lower displacement at dry condition, while the gypsified and natural soils have a moderate values of bearing capacity and relatively low displacements with a little lower values than artificial soil.

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